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THESIS

A SONAR DETECTION MODEL

by

Richard Charles Curley

Thesis Advisor: W. P. Cunningham

March 1971

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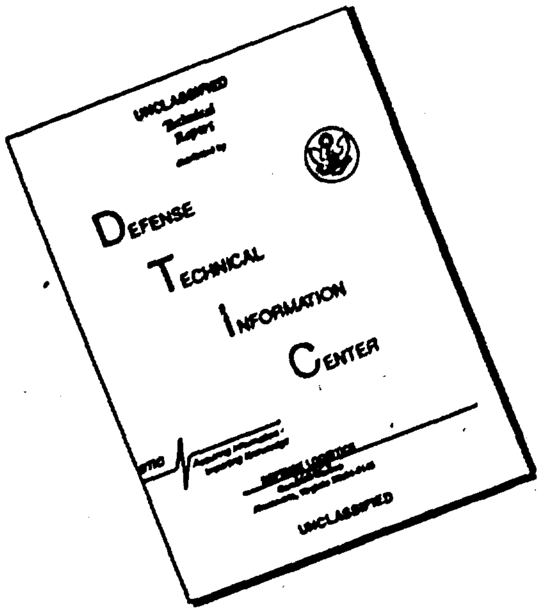

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by

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13. ABSTRACT

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I. INTRODUCTION

Since early in World War II, and more predominantly since the early 1950's, there has been a continuing effort to attain a reliable method of accurately predicting the detection ranges of various sonars, along with the corresponding probabilities of detection, which are in consonance with the values obtained from the evaluation of fleet data. At present, the method which provides one of the better estimates of detection ranges and their corresponding probabilities is the model developed during Project Amos in 1951. This model employs a very simple concept, namely, an operator makes a detection only when the sum of his Figure of Merit plus the target strength are greater than or equal to the losses incurred during the two way propagation of the sound.

The author became acquainted with this model during an experience tour while attending the Naval Postgraduate School. The model was discussed in SAOTM69-3, an Anti-Submarine Warfare Systems Project Office study conducted in 1969. At that time, the model used average values for the Figure-of-Merit and also for the propagation losses. The target strengths employed are shown in Table I, and are the result of studies conducted by National Defense Research Committee in 1946, and the Planning Analysis Group, Office of Naval Operations, in 1963. The model assumes a semi-alert operator would predicate the use of a

semi-alert Figure-of-Merit throughout the running of the model. This model would ultimately produce the detection ranges expected by an operator under those particular circumstances. The author has undertaken the task of modifying the model in order to arrive at a model capable of provoding results which more accurately predict the results obtained in fleet units. The author maintains a more realistic representation is one in which the operator gradually improves his Figure-of-Merit as a result of his having "seen" a target on the previous ping. This process continues until it finally culminates in a detection. The exact method employed in allowing the operator to attain a better value for his Figure-of-Merit will be more fully discussed in Section III. It was hoped that the alteration would enable the model to achieve results which were in consonance with those witnessed in a fleet exercise.

As the newer escort vessels join the fleet with their onboard computers, it becomes a rather simple task for a screen or unit commander to obtain the required information, namely detection ranges, which will enable him to achieve the optimal utilization of his screening forces so as to maximize the anti-submarine protection to the screened body, or area, through the use of this model.

The model as modified in this program consists only of straight line screens with a submarine closing the screening forces on a straight line course. This enables one to employ the geometry associated with right triangles, if it is desired to employ some more exotic type of screening force or to have the submarine travel in something

other than a straight line, then one needs only to rectify the geometry in use in the present edition of the model.

II. STATEMENT OF THE PROBLEM

The problem attacked in this paper was two-fold. The first concern was to provide the individual fleet units with an easy to use method of determining the range at which they may expect to gain their initial detection of an opposing submarine. This is an area in which there is a paucity of information available to the fleet units, and they are normally forced to rely on remembered averages, i.e., they employ the range at which the personnel charged with determining the spacing of the units remember as the most common range at which ships concerned most commonly achieve detection. This method normally leads to an overly optimistic value and results in the screened force having less protection than desired. This use of optimistic detection ranges easily leads to the situation where the probability of penetration of an approaching submarine approaches an unacceptable limit. The use of screening stations as dictated by the various tactical publications is hardly much better. They fail to consider the fact that different personnel man different ships and the ship's detection ranges are not solely dependent upon the type sonar employed or the particular water conditions of the day. The system presently employed in the current publications provides a screen spacing based on the assured sonar range. This spacing is then used until the next time a bathythermagraph reading is reported to the flagship, a time span which may cover four to eight

hours. The ships, if they were to travel at only 15 knots, will cover sixty to 120 nautical miles during this time frame and through a multitude of assured sonar ranges. Some of the newer screens presently employed in the fleet have no information available for the unit commanders to use in order to determine what spacing, or alternatively, how much area a particular ship is capable of covering effectively.

The absence of an ability to estimate ones own detection ranges, and their probabilities (or percentage of occurrences), places an increased burden on the operator, who must now attempt to estimate the best range scale on which to operate. By changing range scales, SAG Report 67-8 implies, it is possible to alter the amount of error in range prediction by up to one hundred per cent. This serves to point up the importance of having some idea as to which range scale to employ in a search.

The second facet of the problem deals with the ability to predict the probabilities associated with given detection ranges for a group of ships. This area requires renewed emphasis in order to be better able to employ our surface units in the protection of convoys or fast carrier attack forces. The availability of a model which would accurately predict the detection probabilities and ranges of a group of ships would be invaluable in assisting a researcher to ascertain the optimal spacing of a screen. This model would also provide the analyst with a means of comparing the relative merits of new screens and tactics as opposed to those already in use.

III. METHODOLOGY

A. ASSUMPTIONS

The following list of assumptions were made in the model. For simplicity they have been divided into three categories.

1. Operational Assumptions (these may be easily varied to simulate different operational conditions).

    a. The submarine is operating in the layer at 12 knots.

    b. The escort is traveling at 15 knots in a straight line.

    c. There is no form of interplay between the ships until a detection is made.

2. Environmental Characteristics (dependent on the weather, sea state, etc.)

    a. The sea is in a state of two.

    b. The layer depth is 150 feet.

3. General Assumptions

    a. The submarine track is of infinite length, and the closest points of approach are uniformly distributed.

    b. A run is concluded when a unit first makes a detection.

    c. It is considered a missed detection whenever a submarine reaches the closest point of approach without having been previously detected.

    d. The sonar operator is employing the 20 thousand yard range scale.

The last assumption is not a particularly valid one since the Figure of Merit employed in the model is taken from data resulting from an operator using the 10 thousand yard range scale. These data were then extrapolated in order to cover the range from zero to twenty thousand yards. This extrapolation will necessarily introduce some errors into the results obtained. It is felt this discrepancy will not result in any errors which are of greater degree than the errors resulting from the methods employed in obtaining the data, and arriving at the Figure of Merit used in the model.

B. PROCEDURES

The first step in calculating the Figure of Merit to be used was the recording of the minimum detectable echo level for various units participating in an exercise. This is obtained on board ship in the following manner: while the operator is operating on a ten thousand yard sonar range scale, the supervisor will go to the area on the equipment designated for this measurement and input a signal. The supervisor then increases the intensity of this signal until the operator makes a detection. This was done when the operator was in both a semi-alerted and fully-alerted state. For some units this information was also recorded when the operator was employing a twenty thousand yard range scale. The source levels for the participating ships was found to vary between 133dB and 137dB. The author opted to use 135dB as the mean source level to apply a variance of 2dB.

The form of the available data, taken from the SHAREM exercises, was such that the number of data points varied between ships and also between the ranges at which they were measured. The weighted averages for the minimum detectable echo level was found at three, five, and eight thousand yards for each ship. This was done for both the semi-alerted and fully-alerted states. The author's next step was to calculate the grand mean for all the ships and the associated variances for all the aforementioned ranges. These values were plotted on a graph, Figures 1 and 2 respectively, and a curve was constructed through the points. A third graph was plotted for the semi-alert operators using the twenty thousand yard range scale in Figure 3.

The curve was divided into three or more segments and a straight line approximation was fitted to these segments. The formulas used for the approximations were calculated to insure a resulting variation of less than two decibels.

The model was run as originally designed using the newly calculated Figure-of-Merit values, and the results were decidedly similar to the results of previous runs, i.e., the results produced a probability of detection of 1.0 at ranges from three to five thousand yards. This led the author to hypothesize the average fleet sonar operator is never really in an initial semi or fully-alerted state. It was further assumed the operator would always start in an unalerted state. He would remain in this state until he detected the first presentation on his scope. At this time the operator would become semi-alerted, and he would

remain in this state until the next presentation is depicted on the display. The operator now attains the fully-alerted condition and upon the occurrence of still further presentations the operator will ultimately achieve a detection. The question which arises at this time is how many presentations must occur while the operator is fully-alerted in order to arrive at a detection.

In order to test this hypothesis it was necessary to obtain a curve for the unalerted operator's Figure-of-Merit. This curve was received from ASWSPO. As was done for the semi and fully-alerted curves, this curve was approximated by straight line segments and these approximations were applied to the model, Figure 4.

The next step required the running of the model. The model was now of the form:

Signal Excess = Figure-of-Merit plus target strength minus twice the one way propagation loss

and was run under a variety of situations. These required the use of subroutines which employ Figure-of-Merit of varying degrees of alertness, from unalert, to semi-alert, etc. From previous work the author was able to ascertain if the model was run in any one state, i.e., an operator only semi-alerted, the result would yield 100% detection at a range of from three to five thousand yards, Figures 5 and 6. In an effort to adjust the results to more closely align with those attained by fleet units, the values of semi-alerted and fully-alerted operators were combined in one model. This same step was also taken

incorporating the two previously stated operator conditions with that of an unalerted operator. These two variations were run in such a manner as to require the operator to attain a "detection" in each of the states prior to attaining the next higher level of alertness. It was now possible to run the program utilizing the two different modes just discussed with varying closest points of approach. The reasoning behind the use of different CPA's was to be able to determine the probabilities of detection associated with these different CPA's at various ranges. This led to the attainment of an accurate probability of detection curve. These values were then plotted, for the three step model, in Figure 7, depicting a mean detection probability for a given range. The method of attaining the curve will be more fully discussed in the discussion of results.

Once the model was workable in the aforementioned configurations, the number of detections required of an operator upon attaining the fully-alerted state were varied in an effort to ascertain the actual number required.

The model was again reconstructed in order to demonstrate the feasibility of its operation when one employs more than one ship. The particular configuration chosen was an arbitrary one of four ships in a straight line with spacing of four thousand yards between ships. In its present form the multi-ship model provides an overly optimistic result, Figure 8, however, this result should become more in consonance with the fleet outcomes as the screen configurations are altered to more

closely approximate the fleet formations and mutual interference is considered.

Finally both the single ship and multi-ship models were run with the target strengths obtained from NAVWEPS Report 8989. These values were for an SSN target and were determined in 1963. The results for the single ship runs, each run consisting of three hundred iterations at each of eleven CPA's (.1, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 thousand yards) were plotted in Figure 7. The multi-ship run, which required three hundred iterations also, was run at one purely arbitrary CPA and is plotted in Figure 8.

IV. DISCUSSION OF RESULTS

In order to achieve the values plotted as the cumulative detection probabilities, the following formula was employed:

$$P(r) = p_d\,[1-P(r+\Delta r)] + P(r+\Delta r)$$

where:

$P(r)$	=	probability of detection by range r
p_d	=	the ratio of the number of targets detected in the interval $(r, r+\Delta r)$ to the number of targets undetected by $r+\Delta r$.
$P(r+\ r)$	=	probability of detection by range $r+\Delta r$, where Δr was always equal to 1000 yards

This formula allowed the author to combine the values determined by the various runs and attain an overall detection probability curve.

The fact the CPA's were assumed to be uniformly distributed allowed the values to be equally weighted.

The resultant curves are not in agreement with the exercise curve at the tails. This can best be explained as a result of not conducting the runs with CPA's greater than ten thousand yards. This constraint tends to limit somewhat the number of observations in excess of ten thousand yards. The data obtained both by the author and in previous simulation (SAOTM 69-3) indicate a respectable number of detections will occur within one thousand yards of CPA as the range increases out to about fifteen thousand yards after which the number of detections would be small. In the results obtained by the author the [illegible]

detections obtained within one thousand yards of CPA, when the CPA was ten thousand yards was approximately one-fourth, and for a nine thousand yard case it was about one third. These facts imply if the model were run with greater CPA's the probabilities of detection in the tail of the curve would be increased to more closely agree with the exercise data. These values were not obtained since the more important results were the values attained at shorter ranges. These values are considered more important since the detection probabilities are more acceptable, and the ranges more likely to be used in the fleet.

The results attained from using the one step model, always semi-alerted, etc., was in considerable disagreement with the exercise data as seen in Figures 5 and 6. The two step model resulted in very similar curves and hence was not plotted but quickly discarded in favor of the three step model.

The three step model, i.e., unalerted, semi-alerted, then fully alerted, produced a cumulative detection probability which was reasonably close to the exercise data, when employing the target strengths from NRDC, 1946. The maximum difference between the two curves, when only one detection was required while fully alerted was 26 percentage points. This value was at a range of five thousand yards and equal to a 37 percent error. The average error was found to be 11.2 percent.

When one considers the error between the use of a twenty thousand yard scale and a ten thousand yard scale as capable of producing a seven decibel difference, and the standard deviation is on the order of

five decibels then an error in detection prediction of thirty-seven percent can be accepted.

When the model, with the NRDC target strengths, was run requiring two detections in the fully alerted state the only change was the shifting of the curve to the left. Since the only problem with the first runs was the high discrepancies in detection probabilities in the four to six thousand yard range interval (from .21 at six thousand yards to maximum .26 at five thousand yards) a comparison was not made with the second run. It should be noted if one only intends to minimize the size of the error, or percent of error, between the exercise data and the model's results one can find a number, n, of required detections, once fully alerted to achieve this goal. This was not the author's goal and this was not therefore pursued.

Next the results were calculated from the running of the model with the NAVWEPS target strengths. These values were normally lower than those resulting from fleet exercises. The maximum error in this case occurs at zero range and is forty-four percentage points. This is an underestimation of fleet data of fifty-four percent. However, in the area of highest error under previous runnings the amount of errors was only eight to thirteen percentage points or approximately a twenty percent underestimation.

This led the author to the conclusion, the figure of merits, although not entirely accurate and contributing to some of the error, were not the greatest concern at present. The greatest single problem seems

to be the inability to accurately predict a target's echo strength. The importance of this cannot be overemphasized. The results attained by the two runs when the different target strengths were used varied by as much as thirty-five percentage points and between zero and eight thousand yards there was an average of thirty-three percentage points difference. These values result in a maximum of fifty-four percent difference and an average difference of forty-five percent. All this resulting from a change in target strength of, on the average, less than two decibels in the area from 0° to 90°, and this is the area of primary interest. This value is less than the smallest deviation used in calculating the figure of merit. These results serve to point up the need for an accurate measurement of the target strength of a submarine. It is felt the model is as accurate as possible for average values until there is more work done in determining target strengths of various submarines.

As for possible use by fleet units, providing they are able to determine accurate values for the figure of merit and recall the discrepancies in the five to six thousand yard range it is feasible to use this model, and results will give an indication of the ship's capabilities.

There was no attempt made to show anything other than a possible method of construction in the multi-ship model. Mutual sonar interference, and baffle areas were not considered. It is recommended as a follow on study to alter the multi-ship model in such a manner as to geometrically portray the screens presently in use. By using average

values for the figure of merit, one may determine the optimal spacing with prescribed limits to achieve the greatest protection to a force.

It is further recommended ships keep a record of each operator's figure of merit, in unalerted, semi-alerted and fully alerted states in much the same manner as radarmen presently measure ping time on a watch-to-watch basis.

TABLE I

Target Strengths

A. National Defense Research Committee

Relative Bearing (degrees)	Target Strength (dB)	Relative Bearing (degrees)	Target Strength (dB)
0-5	8	85-95	24
5-15	11	95-105	20
15-25	17	105-115	16
25-35	16	115-125	15
35-45	15	125-135	15
45-55	15	135-145	16
55-65	15	145-155	16.5
65-75	16	155-165	17
75-85	20	165-175	14

B. NAVWEPS Report 8989

Relative Bearing (degrees)	Target Strength (dB)	Relative Bearing (degrees)	Target Strength (dB)
0-10	9	90-100	24
10-20	10.5	100-110	17.5
20-30	11	110-120	12.5
30-40	10.5	120-130	10.5
40-50	10	130-140	10
50-60	11	140-150	10
60-70	14	150-160	11
70-80	18	160-170	10
80-90	24	170-180	8

Mean Semi-Alerted Figure of Merit

With One Standard Deviation

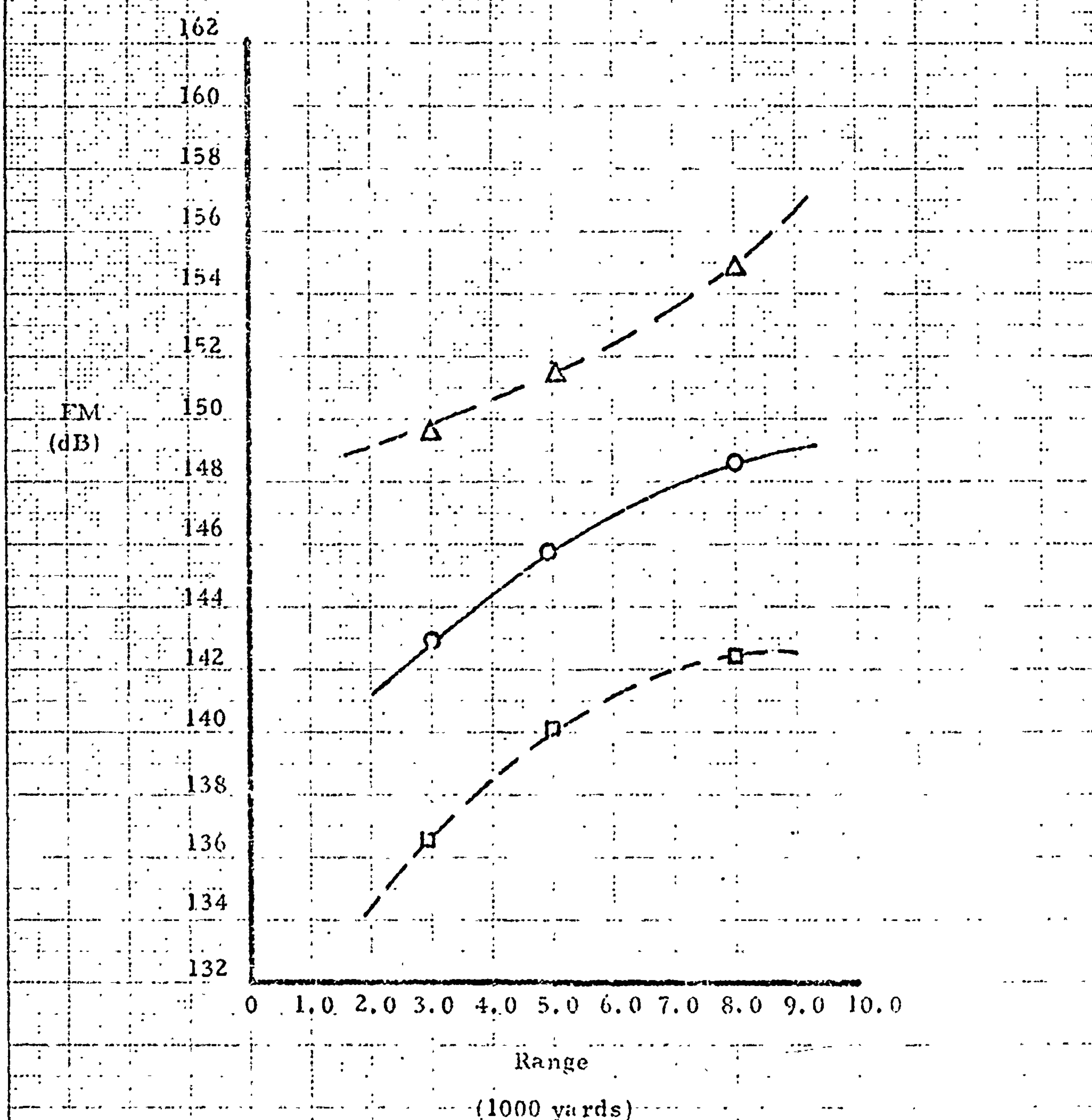


FIGURE I

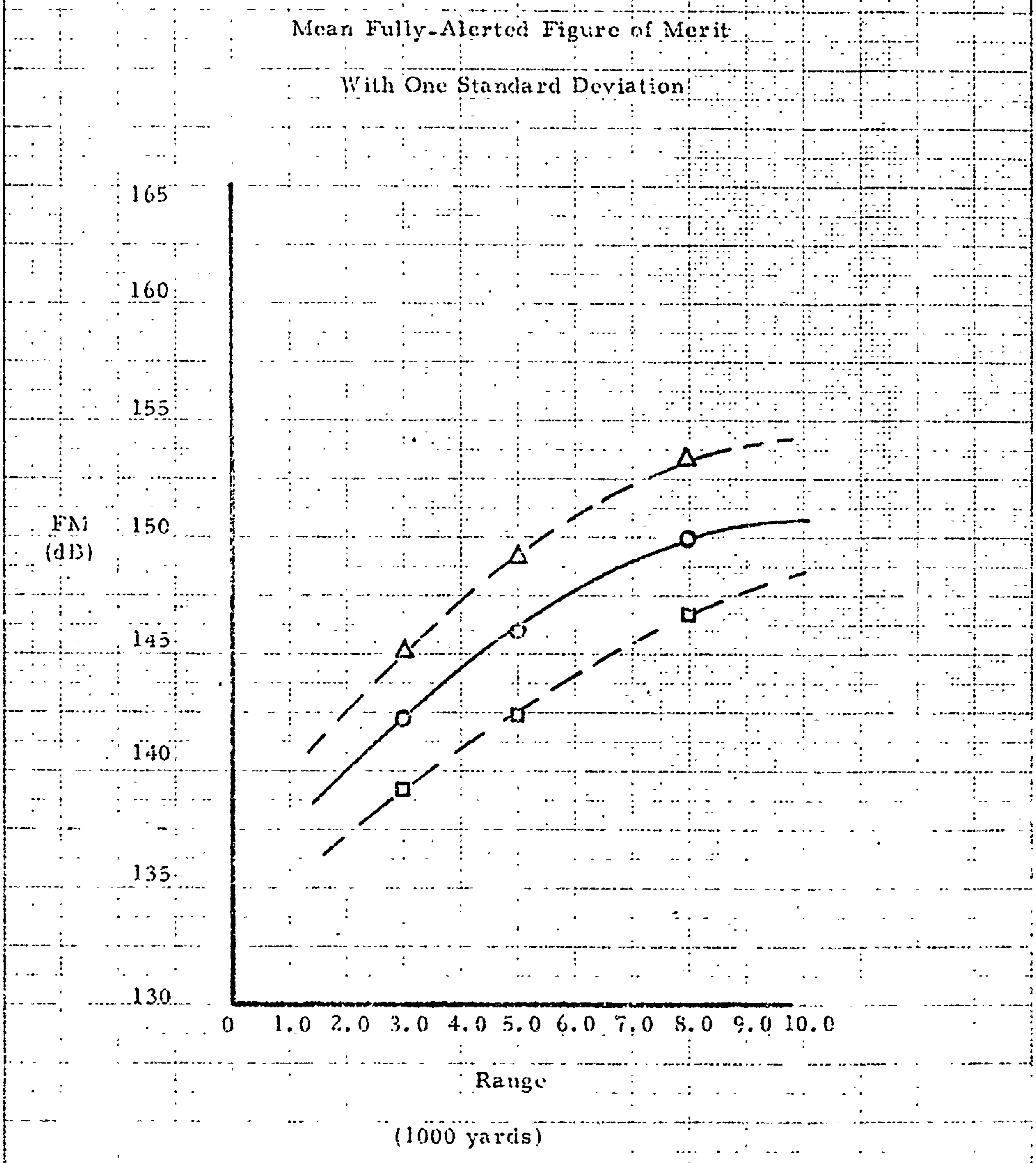
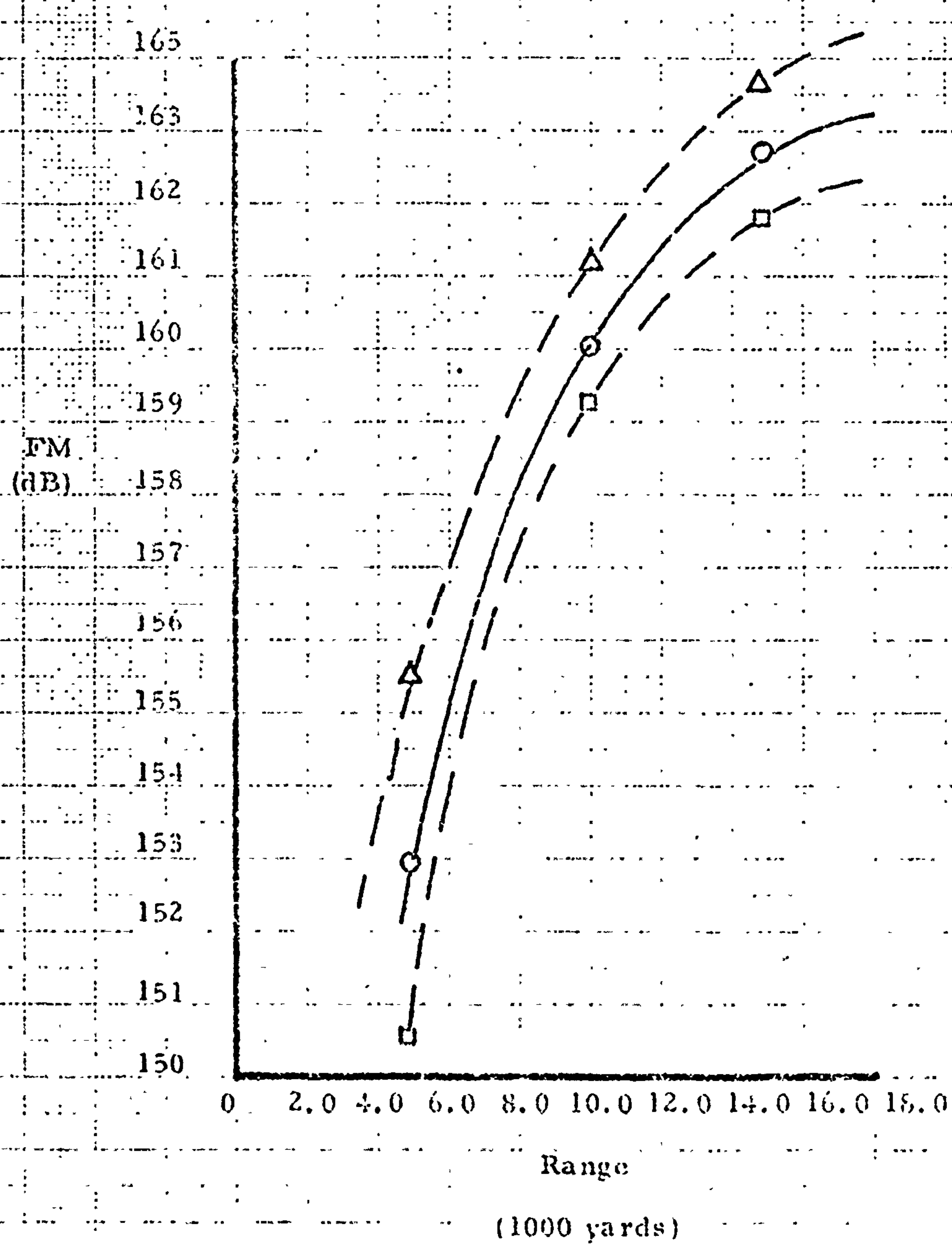

Mean Fully-Alerted Figure of Merit
With One Standard Deviation
FM
(dB)
165
160
155
150
145
140
135
130
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Range
(1000 yards)

FIGURE 2

Mean Semi-Alerted Figure of Merit

With One Standard Deviation



a) 20,000 yard range scale

b) 2 ships

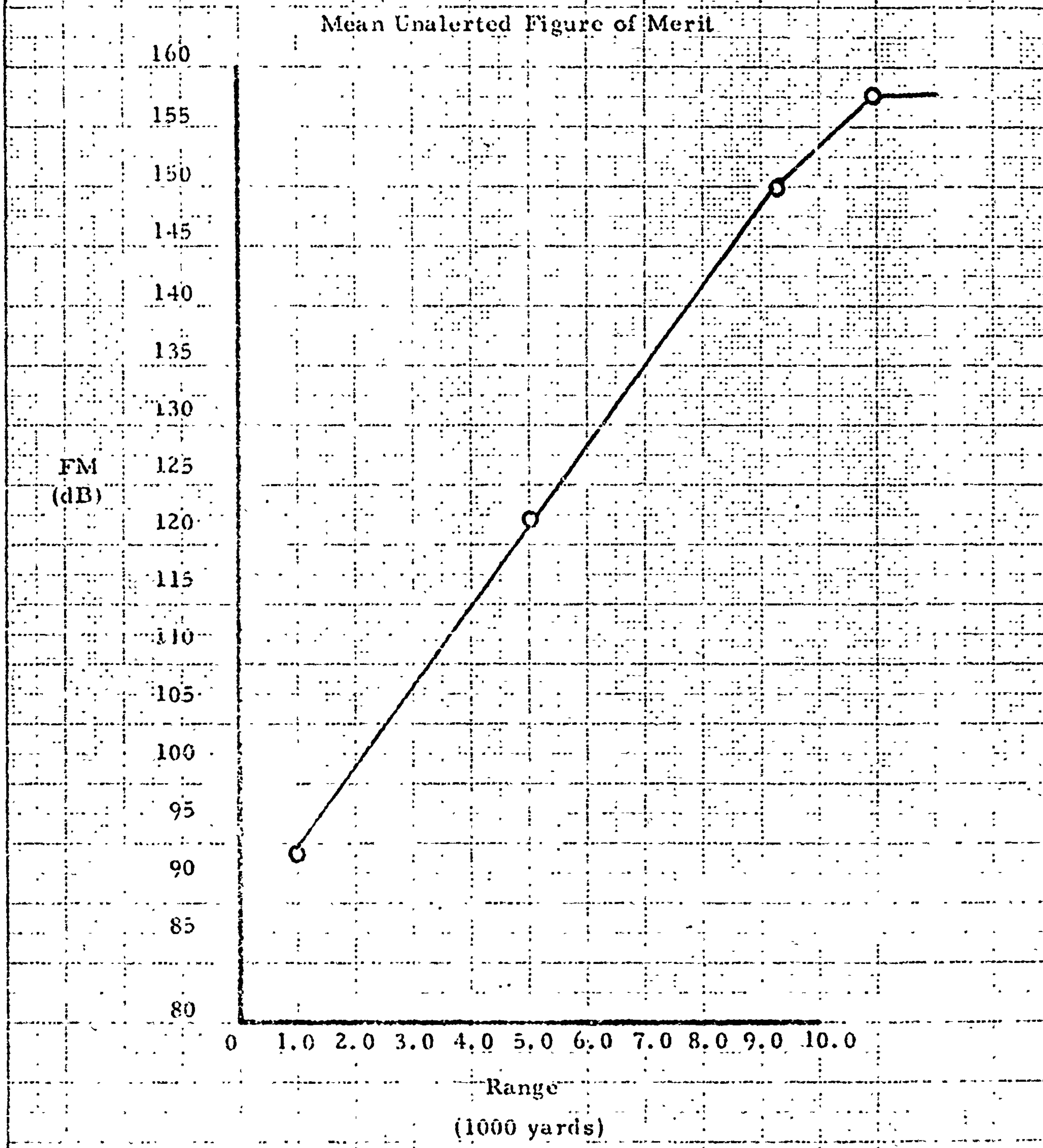

Mean Unalerted Figure of Merit
FM
(dB)
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Range
(1000 yards)

FIGURE 4

Cumulative Probability of Detection

Original Model (CPA = 500 yards)

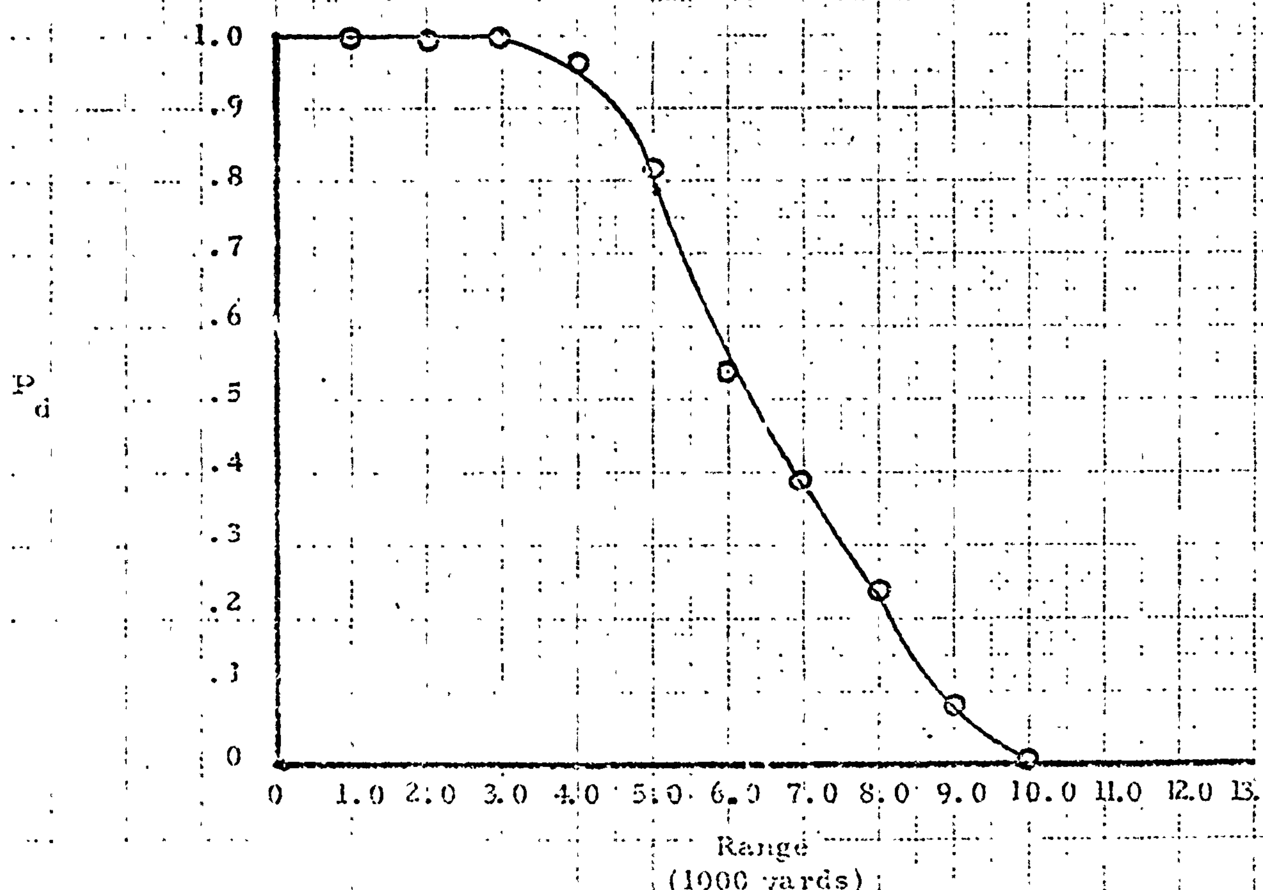


FIGURE 5

Cumulative Probability of Detection

Original Model (CPA = 2000 yards)

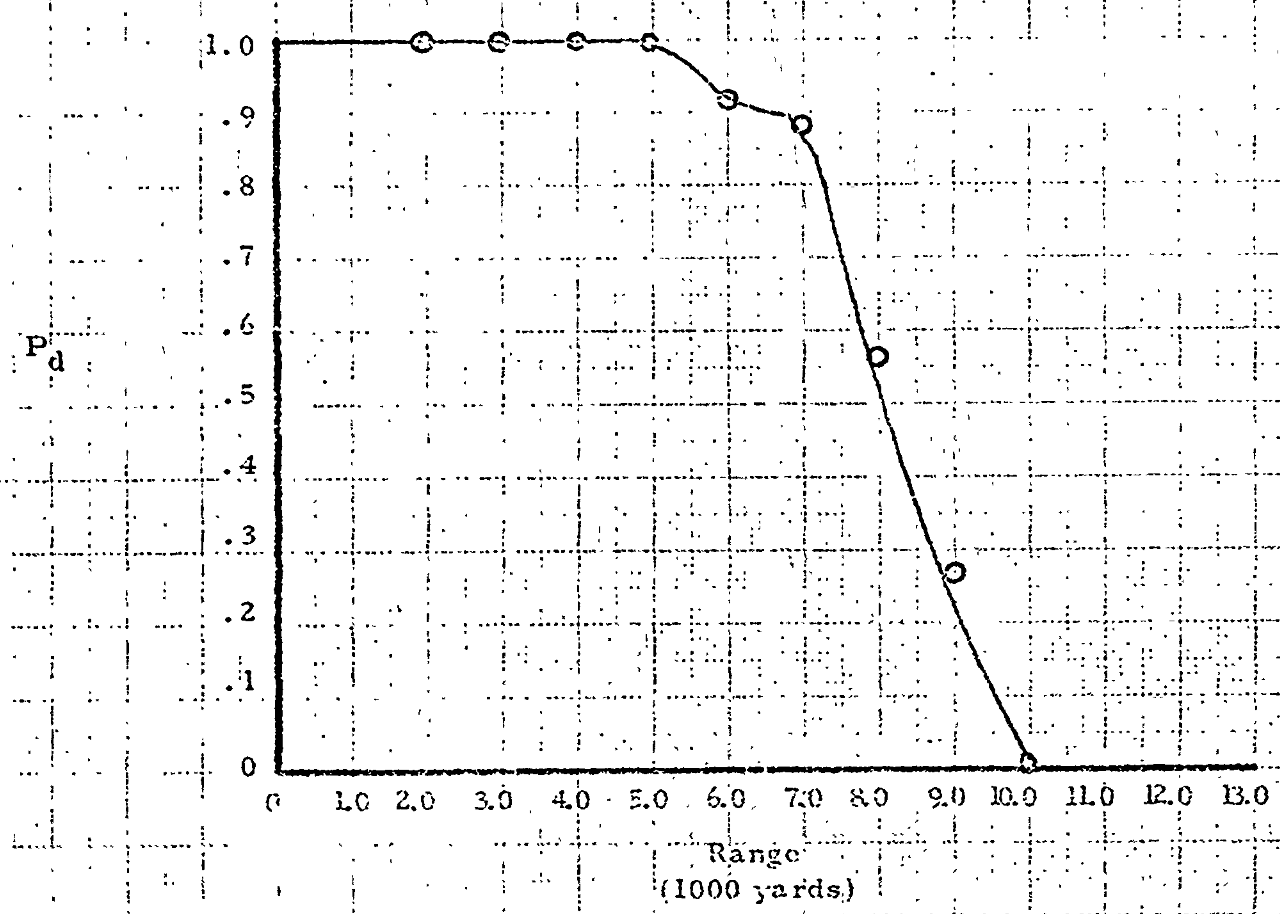


FIGURE 6

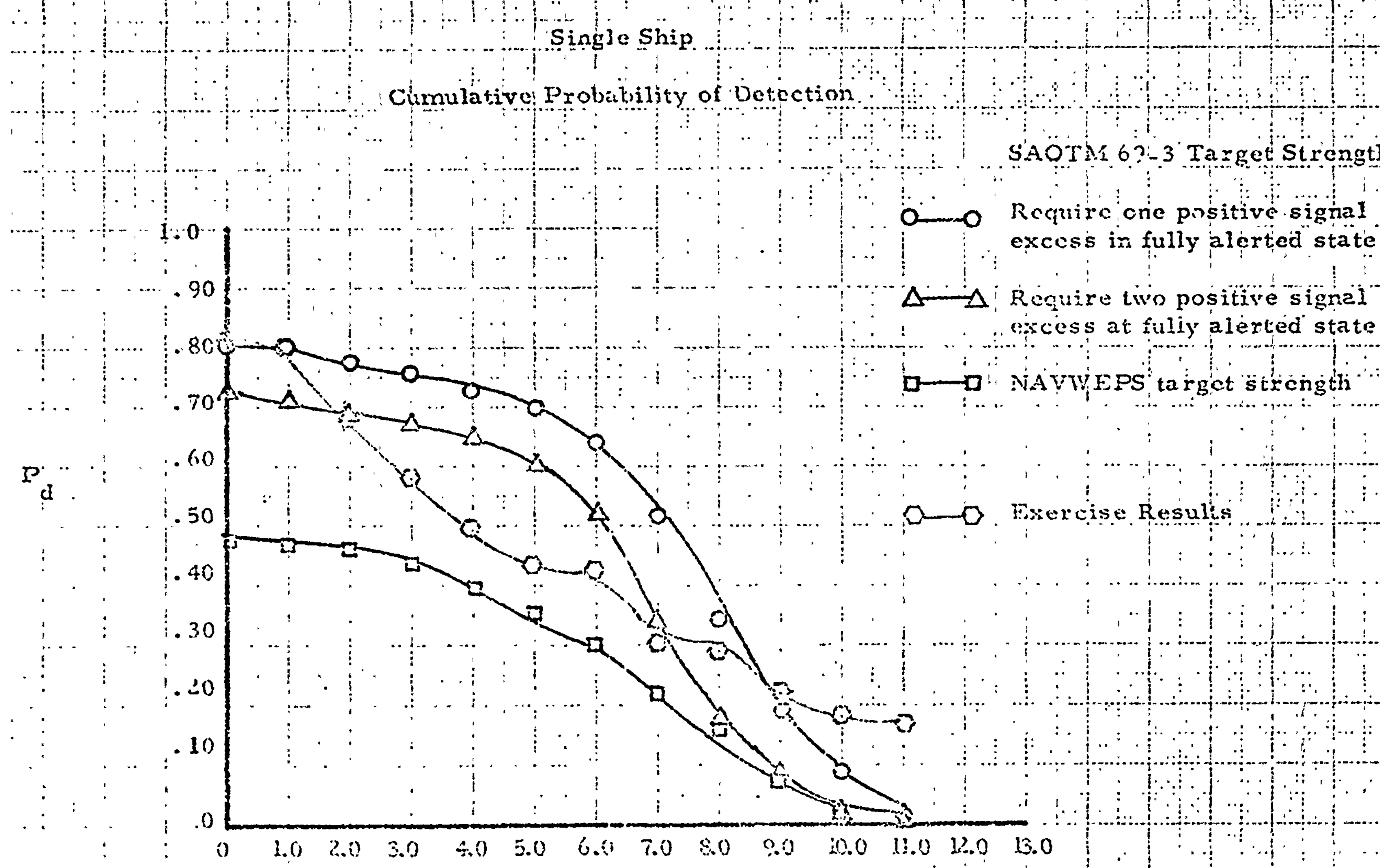

Single Ship
Cumulative Probability of Detection
SAOTM 6?-3 Target Strength
Require one positive signal excess in fully alerted state
Require two positive signal excess at fully alerted state
NAVWEPS target strength
Exercise Results
P_d
1.0
.90
.80
.70
.60
.50
.40
.30
.20
.10
.0
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0

FIGURE 7

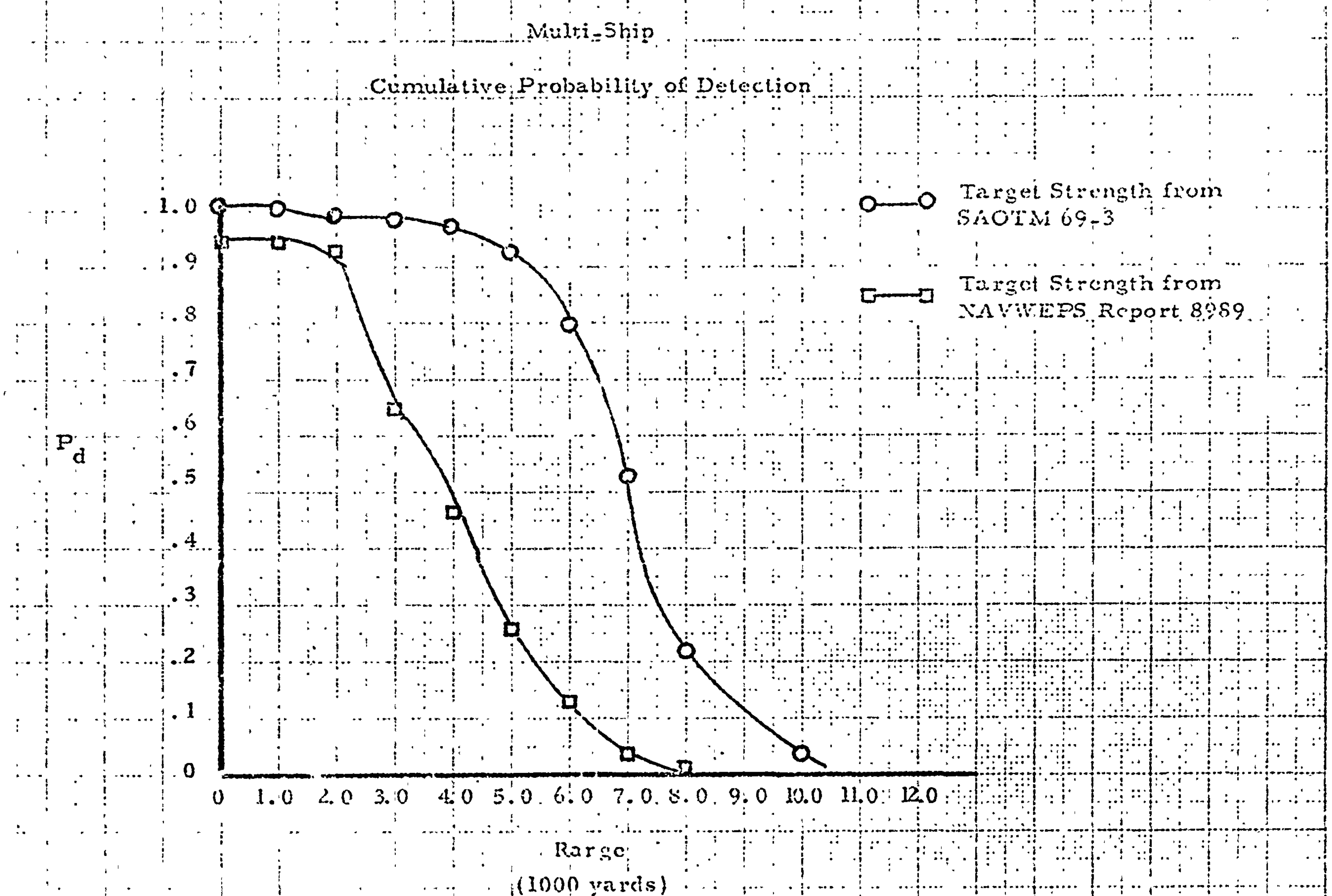

Multi-Ship
Cumulative Probability of Detection
Target Strength from SAOTM 69-3
Target Strength from NAVWEPS Report 8989
P_d
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
Range
(1000 yards)

FIGURE 8

COMPUTER PROGRAM SYMBOLS

All distances are in thousands of yards

RO-	original range of submarine
V-	relative velocity (yards/second)
P-	ping interval (in seconds)
W1-	indicator of above or below the layer 1=below layer 2=in layer
S1-	standard deviation on figure of merit
S2-	standard deviation on propagation loss
S3-	standard deviation on target strength
YO-	original distance from target to CPA on straight line track
Y-	calculated distance from target to CPA on straight line track as problem progresses
R-	distance from ship to target
B-	distance from "prime" ship to CPA (for multi-ship other ships use a function of B)
C-	bearing to target from beam (CPA)
UFI-	unalerted figure of merit
FM1-	figure of merit
OWLI-	one way propagation loss
TSI-	target strength
E1-	unalerted signal excess
E2-	semi-alerted signal excess
E3-	fully-alerted signal excess

SINGLE SHIP MODEL

```
      CALL URN(0)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      DO 2000 L=1,11
      READ(5,724)B
724   FORMAT(F4.2)
      DO 1000 M=1,300
      S=M
      U=0
      D=V*P
      YC=SQRT(RO**2-B**2)
      Y=0
      D1=URN(1)
      Y=YC-(V*P*D1)
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+B**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/B)
      IF (R.LE.1.0) GO TO 200
      IF (R.GE.12.00) GO TO 210
      IF (R.LE.9.00) GO TO 220
      UF1 = 148.6+ 3.00*(R-9.00)
      GO TO 420
200   UF1 =80.0
      GO TO 420
210   UF1= 158.0
      GO TO 420
220   UF1= 93.4+7.00*(R-1.00)
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
```

```
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 205 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
205   CONTINUE
      FM1=UF1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      YM=Y
801   CALL SEMI(YM,YO,D,Y1,Y2,Y3)
      Y=YM
903   R=SQRT(Y**2+B**2)
      C=57.3*ATAN(Y/B)
      WRITE(6,751)R,C
751   FORMAT(/T5,F10.2,2X,F10.2)
1000  CONTINUE
2000  CONTINUE
      STOP
      END

      SUBROUTINE SEMI (YM,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      Y=YM
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+B**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/B)
```

```
      IF(R.LE.8.0) GO TO 390
      IF(R.GT.15.0)GO TO 410
      F1=(1.2*R)+139.4
      GO TO 420
390   F1=(5.4*R)+105.8
      GO TO 420
410   F1=157.4
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.0*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF(E2.LE.0.0) GO TO 160
      YM=Y
```

```
801   CALL FULL  (YM,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE FULL (YM,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,3
      DIMENSION Q(3)
      N=0.0
      Y=YM
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+B**2)
      C=57.3*ATAN(Y/B)
      IF (R.LE.4.00) GO TO 245
      IF (R.GT.6.50) GO TO 255
      IF (R.GT.8.CO) GO TO 265
      F1=138.0 +2.2*R
      GO TO 420
245   F1=135. + 2.2*R
      GO TO 420
255   F1= 142.0 + 0.9*R
      GO TO 420
265   F1= 149.0 +C.1*R
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.1C.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.4.00) GO TO 625
      IF (R.GT.6.50) GO TO 630
      IF(R.GT.8.00) GO TO 650
      S1 =3.5
      GO TO 660
625   S1=3.1
      GO TO 660
```

```
630   S1=3.4
      GO TO 660
650   S1=3.0
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013026*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 824
      IF(E3.LE.0.0) GO TO 160
824   YM=Y
      RETURN
      END

      BLOCK DATA
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DATA T,RO,V,P,W1,S2,S3/9.,10.5,11.,10.5,10.,11.,14.,18.,24.,24.,17
     1.5,12.5,10.5,10.,10.,11.,10.,8.,20.,0.015,24.,2.,3.5,2.0/
      END
```

MULTI-SHIP MODEL

```
      CALL URN(0)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      DO 1000 M=1,300
      S=M
      U=0
      D=V*P
      YO=SQRT(RO**2-B**2)
      Y=0
      D1=URN(1)
      Y=YO-(V*P*D1)
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+B**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/B)
      IF (R.LE.1.0) GO TO 200
      IF (R.GE.12.00) GO TO 210
      IF (R.LE.9.00) GO TO 220
      UF1 = 148.6+ 3.00*(R-9.00)
      GO TO 420
200   UF1 =80.0
      GO TO 420
210   UF1= 158.0
      GO TO 420
220   UF1= 93.4+7.00*(R-1.00)
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 590
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
```

```
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 205 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
205   CONTINUE
      FM1=UFI+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      YM=Y
801   CALL SEMI(YM,YO,D,Y1,Y2,Y3)
      Y=YM
      IF(Y1.GE.Y) GO TO 901
906   IF(Y2.GE.Y3)  GO TO 902
      IF(Y.GE.Y3) GO TO 903
      R=SQRT(Y3**2+B**2)
      C=57.3*ATAN(Y3/B)
      GO TO 960
901   IF(Y1.GE.Y3) GO TO 904
      GO TO 906
902   IF(Y1.GE.Y2) GO TO 903
      IF(Y.GE.Y2) GO TO 903
905   R=SQRT(Y2**2+B**2)
      C=57.3*ATAN(Y2/B)
      GO TO 960
903   R=SQRT(Y**2+B**2)
      C=57.3*ATAN(Y/B)
      GO TO 960
904   IF(Y1.LE.Y2) GO TO 905
      R=SQRT(Y1**2+B**2)
      C=57.3*ATAN(Y1/B)
960   TWL1=2*OWL1
      WRITE(6,745)
745   FORMAT(//T10,'RUN NO.',5X,'PING NO.',4X,'RANGE',7X,'BEARING',5X,'S
```

```
     1HIP  M RANGE',2X,'SHIP 1  RANGE',2X,'SHIP 2 RANGE ',2X,'SHIP 3 RAN
     2GE')
      WRITE (6,750)S,U,R,C,YM,Y1,Y2,Y3
750   FORMAT(T5,F10.2,2X,F10.2,2X,F10.2,2X,F10.2,6X,F10.2,5X,F10.2,5X,F1
     30.2,2X,F10.2)
1000  CONTINUE
      STOP
      END

      SUBROUTINE SEMI (YM,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      Y=YM
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+B**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/B)
      IF(R.LE.8.0) GO TO 390
      IF(R.GT.15.0)GO TO 410
      F1=(1.2*R)+139.4
      GO TO 420
390   F1=(5.4*R)+105.8
      GO TO 420
410   F1=157.4
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
```

```
      GO TO 660
650   S1=4.5
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF(E2.LE.0.0) GO TO 160
      YM=Y
801   CALL FULL  (YM,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE FULL (YM,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      N=0.0
      Y=YM
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+B**2)
      C=57.3*ATAN(Y/B)
      IF (R.LE.4.00) GO TO 245
      IF (R.GT.6.50) GO TO 255
      IF (R.GT.8.00) GO TO 265
      F1=138.0 +2.2*R
      GO TO 420
245   F1=135. + 2.2*R
      GO TO 420
255   F1= 142.0 + 0.9*R
      GO TO 420
265   F1= 149.0 +0.1*R
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
```

```
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.4.00) GO TO 625
      IF (R.GT.6.50) GO TO 630
      IF(R.GT.8.00) GO TO 650
      S1 =3.5
      GO TO 660
625   S1=3.1
      GO TO 660
630   S1=3.4
      GO TO 660
650   S1=3.0
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 824
      IF(E3.LE.0.0) GO TO 160
824   YM=Y
925   CALL SHIP1(Y,Y0,D,Y1,Y2,Y3)
      RETURN
      END
```

```
      SUBROUTINE  SHIP1(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      D1=URN(1)
      U=0.0
      Y=YO-V*P*D1
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+(B+8.0)**2)
      C=57.3*ATAN(Y/(B+8.0))
      IF (R.LE.1.0) GO TO 200
      IF (R.GE.12.00) GO TO 210
      IF (R.LE.9.00) GO TO 220
      UF1 = 148.6+ 3.00*(R-9.00)
      GO TO 420
200   UF1 =80.0
      GO TO 420
210   UF1= 158.0
      GO TO 420
220   UF1= 93.4+7.00*(R-1.00)
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 205 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
```

```
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
205   CONTINUE
      FM1=UF1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      Y1=Y
 801  CALL SEMI1 (Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE SEMI1(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      Y=Y1
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+(B+8.0)**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(B+8.0))
      IF(R.LE.8.0) GO TO 390
      IF(R.GT.15.0)GO TO 410
      F1=(1.2*R)+139.4
      GO TO 420
390   F1=(5.4*R)+105.8
      GO TO 420
410   FI=157.4
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
```

```
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      &&&OCL&C-1C - &- T-  01
      IF(E2.LE.0.0) GO TO 160
      Y1=Y
801   CALL FULL1 (Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE FULL1(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      N=0.0
      Y=Y1
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+(B+8.0)**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(B+8.0))
      IF (R.LE.4.00) GO TO 245
      IF (R.GT.6.50) GO TO 255
      IF (R.GT.8.00) GO TO 265
      F1=138.0 +2.2*R
      GO TO 420
245   F1=135. + 2.2*R
```

```
      GO TO 420
255   F1= 142.0 + 0.9*R
      GO TO 420
265   F1= 149.0 +0.1*R
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.4.00) GO TO 625
      IF (R.GT.6.50) GO TO 630
      IF(R.GT.8.00) GO TO 650
      S1 =3.5
      GO TO 660
625   S1=3.1
      GO TO 660
630   S1=3.4
      GO TO 660
650   S1=3.0
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      CWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*CWL1
      IF(Y.LE.-1.5) GO TO 925
      IF(E3.LE.0.0) GO TO 160
824   Y1=Y
```

```
925   CALL SHIP2(Y,YO,D,Y1,Y2,Y3)
900   RETURN
      END

      SUBROUTINE  SHIP2(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      U=0.0
      D1=URN(1)
      Y=YO-V*P*D1
160   Y=Y-D
      U=U+1
      R=SQRT(Y**2+(4.0-B)**2)
      C=57.3*ATAN(Y/(4.0-B))
      IF (R.LE.1.0) GO TO 200
      IF (R.GE.12.00) GO TO 210
      IF (R.LE.9.00) GO TO 220
      UF1 = 148.6+ 3.00*(R-9.00)
      GO TO 420
200   UF1 =80.0
      GO TO 420
210   UF1= 158.0
      GO TO 420
220   UF1= 93.4+7.00*(R-1.00)
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
```

```
650   S1=4.5
660   DO 205 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
205   CONTINUE
      FM1=UF1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      Y2=Y
801   CALL SEMI2 (Y,YO,D,Y1,Y2,Y3)
      RETURN
      END


      SUBROUTINE SEMI2(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      Y=Y2
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+(4.0-B)**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(4.0-B))
      IF(R.LE.8.0) GO TO 390
      IF(R.GT.15.0)GO TO 410
      F1=(1.2*R)+139.4
      GO TO 420
390   F1=(5.4*R)+105.8
      GO TO 420
410   F1=157.4
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
```

```
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF(E2.LE.0.0) GO TO 160
      Y2=Y
801   CALL FULL2 (Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE FULL2(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      N=0.0
      Y=Y2
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+(4.0-B)**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(4.0-B))
      IF (R.LE.4.00) GO TO 245
```

```
      IF (R.GT.6.50) GO TO 255
      IF (R.GT.8.00) GO TO 265
      F1=138.0 +2.2*R
      GO TO 420
245   F1=135. + 2.2*R
      GO TO 420
255   F1= 142.0 + 0.9*R
      GO TO 420
265   F1= 149.0 +0.1*R
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.4.00) GO TO 625
      IF (R.GT.6.50) GO TO 630
      IF(R.GT.8.00) GO TO 650
      S1 =3.5
      GO TO 660
625   S1=3.1
      GO TO 660
630   S1=3.4
      GO TO 660
650   S1=3.0
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      UWL1=AL1+S2*Q(2)
```

```
      TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*OWL1
      IF(E3.LE.0.0) GO TO 160
 824  Y2=Y
 925  CALL SHIP3(Y,YO,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE  SHIP3(Y,YO,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      U=0.0
      D1=URN(1)
      Y=YO-V*P*D1
 160  Y=Y-D
      U=U+1
      R=SQRT(Y**2+(B+4.0)**2)
      C=57.3*ATAN(Y/(B+4.0))
      IF  (R.LE.1.0) GO TO 200
      IF  (R.GE.12.00) GO TO 210
      IF  (R.LE.9.00) GO TO 220
      UF1 = 148.6+ 3.00*(R-9.00)
      GO TO 420
 200  UF1 =80.0
      GO TO 420
 210  UF1= 158.0
      GO TO 420
 220  UF1= 93.4+7.00*(R-1.00)
 420  IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
 470  AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
 490  AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
 510  IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
 550  AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
 570  AL1=(.434294*72.0*ALOG(R))+40.0
 580  K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
```

```
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 205 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
205   CONTINUE
      FM1=UF1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E1=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF (E1.LE.0.0) GO TO 160
      Y3=Y
801   CALL SEMI3 (Y,Y0,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE SEMI3(Y,Y0,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      Y=Y3
160   Y=Y-D
      U=U+1
161   R=SQRT(Y**2+(B+4.0)**2)
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(B+4.0))
      IF(R.LE.8.0) GO TO 390
      IF(R.GT.15.0)GO TO 410
      F1=(1.2*R)+139.4
      GO TO 420
390   F1=(5.4*R)+105.8
      GO TO 420
410   F1=157.4
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
```

```
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.3.0) GO TO 630
      IF (R.GT.15.0) GO TO 650
      S1=5.5
      GO TO 660
630   S1=6.0
      GO TO 660
650   S1=4.5
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423788+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E2=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF(E2.LE.0.0) GO TO 160
      Y3=Y
801   CALL FULL3 (Y,Y0,D,Y1,Y2,Y3)
      RETURN
      END

      SUBROUTINE FULL3(Y,Y0,D,Y1,Y2,Y3)
      COMMON/UNAL/T(18),R0,V,P,W1,S2,S3,B
      DIMENSION Q(3)
      N=0.0
      Y=Y3
160   Y=Y-D
161   R=SQRT(Y**2+(B+4.0)**2)
```

```
      U=U+1
      IF(R.GT.20.0) GO TO 160
      C=57.3*ATAN(Y/(B+4.0))
      IF (R.LE.4.00) GO TO 245
      IF (R.GT.6.50) GO TO 255
      IF (R.GT.8.00) GO TO 265
      F1=138.0 +2.2*R
      GO TO 420
245   F1=135. + 2.2*R
      GO TO 420
255   F1= 142.0 + 0.9*R
      GO TO 420
265   F1= 149.0 +0.1*R
420   IF(W1.EQ.1) GO TO 510
      IF(R.LE.3.0) GO TO 470
      IF(R.GT.10.0) GO TO 490
      AL1=(.434294*39.0*ALOG(R))+51.0
      GO TO 580
470   AL1=(.434294*20.0*ALOG(R))+60.0
      GO TO 580
490   AL1=(.43294*51.0*ALOG(R))+39.0
      GO TO 580
510   IF (R.LE.3.0) GO TO 550
      IF (R.GT.5.0) GO TO 570
      AL1=(.434294*48.8*ALOG(R))+55.7
      GO TO 580
550   AL1=(.434294*32.8*ALOG(R))+63.0
      GO TO 580
570   AL1=(.434294*72.0*ALOG(R))+40.0
580   K=((90-C)/10)+1.0
      IF (R.LE.4.00) GO TO 625
      IF (R.GT.6.50) GO TO 630
      IF(R.GT.8.00) GO TO 650
      S1 =3.5
      GO TO 660
625   S1=3.1
      GO TO 660
630   S1=3.4
      GO TO 660
650   S1=3.0
660   DO 200 J=1,3
      X=URN(1)
      A=SQRT(-2*ALOG(0.5*(1-ABS(1-2*X))))
      A1=(A*(.013028*A+.802853))+2.515517
      A2=1+A*(1.423768+A*(.189269+(.001308*A)))
      Z=A-A1/A2
      IF (X.GT.0.5) GO TO 770
      Z=-Z
```

```
770   Q(J)=Z
200   CONTINUE
      FM1=F1+S1*Q(1)
      OWL1=AL1+S2*Q(2)
      TS1=T(K)+S3*Q(3)
      E3=FM1+TS1-2.0*OWL1
      IF(Y.LE.-1.5) GO TO 801
      IF(E3.LE.0.0) GO TO 160
824   Y2=Y
801   RETURN
      END

      BLOCK DATA
      COMMON/UNAL/T(18),RO,V,P,W1,S2,S3,B
      DATA T,RO,V,P,W1,S2,S3,B/9.,10.5,11.,10.5,10.,11.,14.,18.,24.,24.,
     117.5,12.5,10.5,10.,10.,11.,10.,8.,20.0,0.015,24.,2.,3.5,2.0,02.0/
      END
```

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